JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2001, **75,** 93–106 NUMBER 1 (JANUARY)

OVERMATCHING IN RATS: THE BARRIER CHOICE PARADIGM

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The barrier choice paradigm was used to impose a cost on rats' behavior of traveling between two levers: Pressing on two levers was reinforced with food on concurrent random-interval schedules, but rats had to climb over a barrier to move from one lever to another. The height of the barrier separating the levers was increased from 30.5 to 45.7 cm across two phases that involved various pairs of random-interval schedules. With the 30.5-cm barrier, the generalized matching law showed slopes equal to or slightly above 1.0 for response and time allocation. With the 45.7-cm barrier, the generalized matching law showed slopes above 1.2 for responses, indicating that sensitivity to reinforcement increased with increasing barrier height. For time allocation the slopes remained close to 1.0; sensitivity to reinforcement did not seem to increase with increasing barrier height. The role of locomotion effort in choice situations is discussed.

Key words: overmatching, choice, barrier, locomotion, travel, lever press, rats

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Choice can be studied in the laboratory by exposing organisms to two response alternatives, usually a pair of concurrent variable-interval schedules of food reinforcement (see de Villiers, 1977, for review). The general pattern of results in this choice situation is described by Herrnstein's (1961) matching law,

$$B_1/B_2 = r_1/r_2, \qquad (1)$$

where B_1 and B_2 represent behavior allocated to Alternatives 1 and 2, respectively, and r_1 and r_2 are the reinforcement obtained from Alternatives 1 and 2 as a result of B_1 and B_2.

To account for deviations from Equation 1, Baum (1974) proposed the following equation, termed the generalized matching law:

$$\log B_1/B_2 = s \log r_1/r_2 + \log b, \qquad (2)$$

where s represents sensitivity of the behavior ratio, B_1/B_2, to variation in the reinforcement ratio, r_1/r_2, and b represents a bias in favor of one or the other alternative (Baum, 1974). A value of s less than 1.0 is called *undermatching*, meaning that the changes in the behavior ratio, B_1/B_2, lag behind those taking place in the reinforcement ratio, r_1/r_2. By contrast, a value of s exceeding 1.0, termed *overmatching*, indicates that behavior is disproportionately allocated in favor of the richer schedule of reinforcement (Baum, 1979, 1981).

With standard concurrent VI VI schedules, undermatching has been found more often than overmatching (Davison & McCarthy, 1988). In studies in which the changeover delay (COD), or travel time, between alternatives is excluded from the calculation of time allocated to the alternatives, overmatching has been obtained (e.g., Baum, 1974; Silberberg & Fantino, 1970).

More evidence for overmatching is found in studies in which the duration of the COD was extended (Shull & Pliskoff, 1967) or a fixed-ratio changeover requirement was increased (Pliskoff & Fetterman, 1981). Thus, a growing body of evidence suggests that when the situation imposes a cost on the behavior of moving from one alternative to another, overmatching is the rule. This idea has been supported by experiments in which a standard chamber for pigeons was adapted to include travel (e.g., Baum, 1982; Boelens & Kop, 1983).

Although all of these studies used pigeons as subjects, overmatching has recently been observed with rats in a choice situation in which running was required to move from one lever to another when the levers were separated by a barrier (Baum & Aparicio, 1999). In that situation, the effects of locomotion on choice resembled those of travel

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This research was supported by the National Council of Science and Technology (CONACYT), Grant 28570H. Portions of this paper were presented at the 25th annual convention of the Association for Behavior Analysis, Chicago, 1999. I am grateful to Franscois Tonneau for helpful comments on early versions of this paper.

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simulated in operant analogues of foraging-related choices (Aparicio & Baum, 1997). These studies suggested, however, that more costly travel (i.e., travel with hurdles) might produce stronger overmatching than that caused by simple locomotion. The current study explored this possibility by using the barrier choice paradigm (Aparicio, 1998, 1999), a method designed to increase the difficulty of moving from one place to another.

METHOD

Subjects

Twelve naive male Long-Evans hooded rats (numbered 51 through 62), between 100 and 120 days old, participated as subjects. The rats weighed between 290 and 320 g before starting food deprivation and were maintained at 85% of their free-feeding weights. Water was freely available in the home cages, and the rats were maintained on a 12:12 hr light/dark cycle.

Apparatus

The apparatus has been described in detail elsewhere (Aparicio, 1998, 1999). It consisted of a chamber (38 cm by 35.5 cm) with two retractable response levers (ENV-112) operated by a force of 0.2 N, one on each side of the anterior wall of the chamber. The chamber could be divided in two equal parts by placing a wire mesh barrier between the levers; in such conditions the rats had to climb over the barrier to switch from one lever to the other. An aperture (3 cm wide and 5 cm high), located in the bottom front part of the barrier, allowed rats to obtain food (45-mg Noyes Formula A pellets) from the hopper from either side of the chamber. Two 24-V DC stimulus lights centered 4 cm above the levers and 17 cm above the floor provided ambient illumination. Daily sessions were conducted in a dark room, and extraneous sounds were masked by white noise.

General Procedure

The experiment included two phases corresponding to different heights of the barrier: 30.5 cm in the first phase and 45.7 cm in the second phase.

Phase 1. All rats were trained to lever press for food by using an autoshaping procedure (Brown & Jenkins, 1968). When the rats consistently pressed both levers, the experiment began. A 30.5-cm barrier was placed between the levers. All sessions started by inserting the levers into the chamber and turning on the lights above the levers. Pressing the left or the right lever was reinforced with food according to concurrent schedules with random-interval (RI) components. In different conditions, the rate of reinforcement was varied across levers according to eight pairs of RI schedules: 60-60, 30-90, 15-120, 60-60 (redetermination), 90-30, 120-15, 80-160, and 160-80 s. These numbers were the mean values of 100 intervals generated by the Random function of Turbo Pascal®. Conditions were in effect for at least 30 sessions and until the ratios of responses and reinforcers (left/right) did not vary by more than 5% across five consecutive sessions.

All sessions ended when 60 pellets were produced or after 90 min, whichever came first. To prevent immediate reinforcement of the behavior of switching from one lever to the other, a 1-s COD was programmed. That is, pressing the left or the right lever could produce food only after 1 s had elapsed after switching to this lever.

Phase 2. The general procedure was similar to that in Phase 1, except that a 15.2-cm barrier was mounted on the top of the 30.5-cm barrier to raise its total height to 45.7 cm. The initial four conditions of Phase 2 used the same pairs of RI schedules (60-60, 30-90, 15-120, and 90-30) as at the start of Phase 1. Then the following pairs of RI schedules were used: 120-90, 160-50, 225-135, 45-75, and 75-45. Four animals, however, died during Phase 2. Rats 53 and 61 died of respiratory illness; Rat 59 died after breaking its teeth on the bars of its cage; Rat 60 was sacrificed when it was noticed that its teeth had grown abnormally and it had stopped eating.

Data Analysis

For each lever, the following dependent variables were computed: number of lever presses, number of changeovers from one lever to the other, travel time, and residence time. Travel time was defined as the interval between the last response on one lever and the first response on the other lever. Residence time was computed from the first response on one lever to the last response on

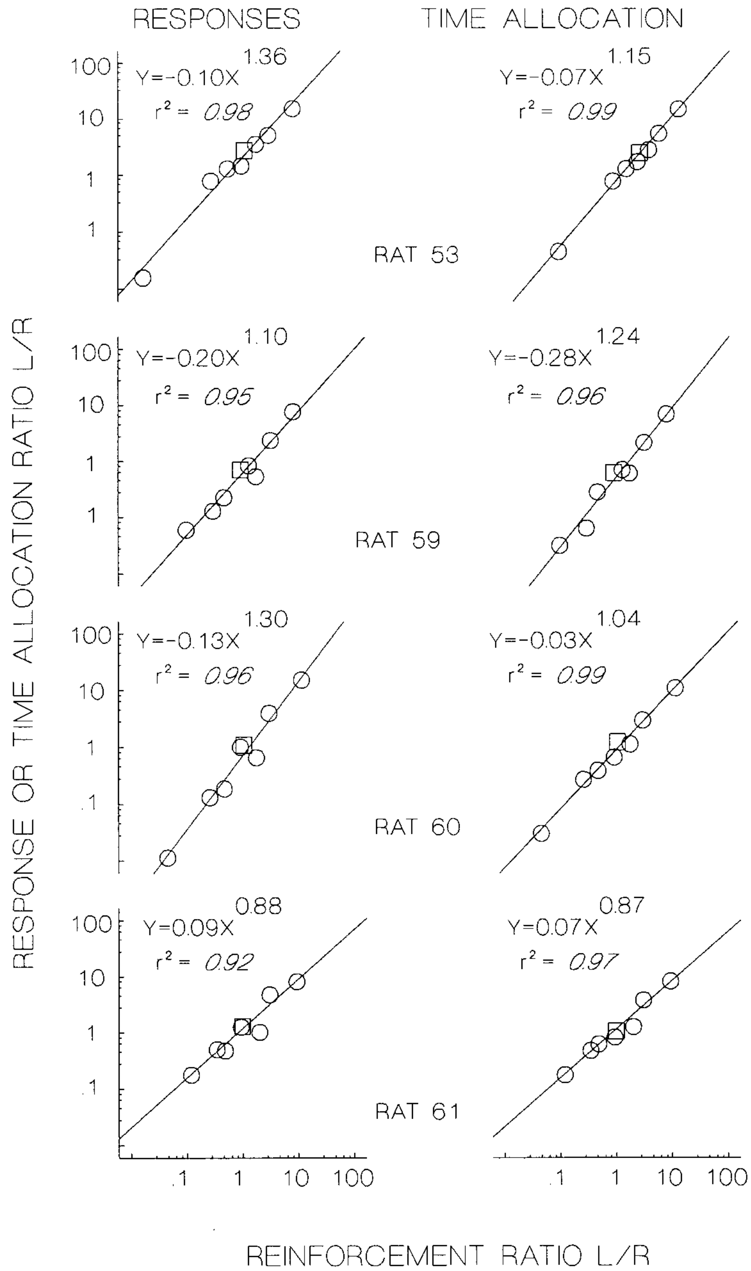

Fig. 1. The ratios (left/right) of responses (left panels) and time allocation (right panels) for each rat that participated in Phase 1 only, plotted on log-log coordinates. Response and time-allocation ratios are shown as a function of obtained (left/right) reinforcer ratios (note logarithmic scales on *x* and *y* axes). Each circle represents the mean data obtained from a pair of RI schedules. The squares represent redeterminations of the 60-60 pair. The solid lines were fitted by using Equation 2. The resulting equations appear above the fitted lines.

the same lever. Data from the last 5 days of each condition were averaged and used in the analysis of the results (see Appendixes A and B).

For each pair of RI schedules, the ratios (left/right) of responses, reinforcers, and residence time were computed and transformed into logarithms of base 10. The logarithms of

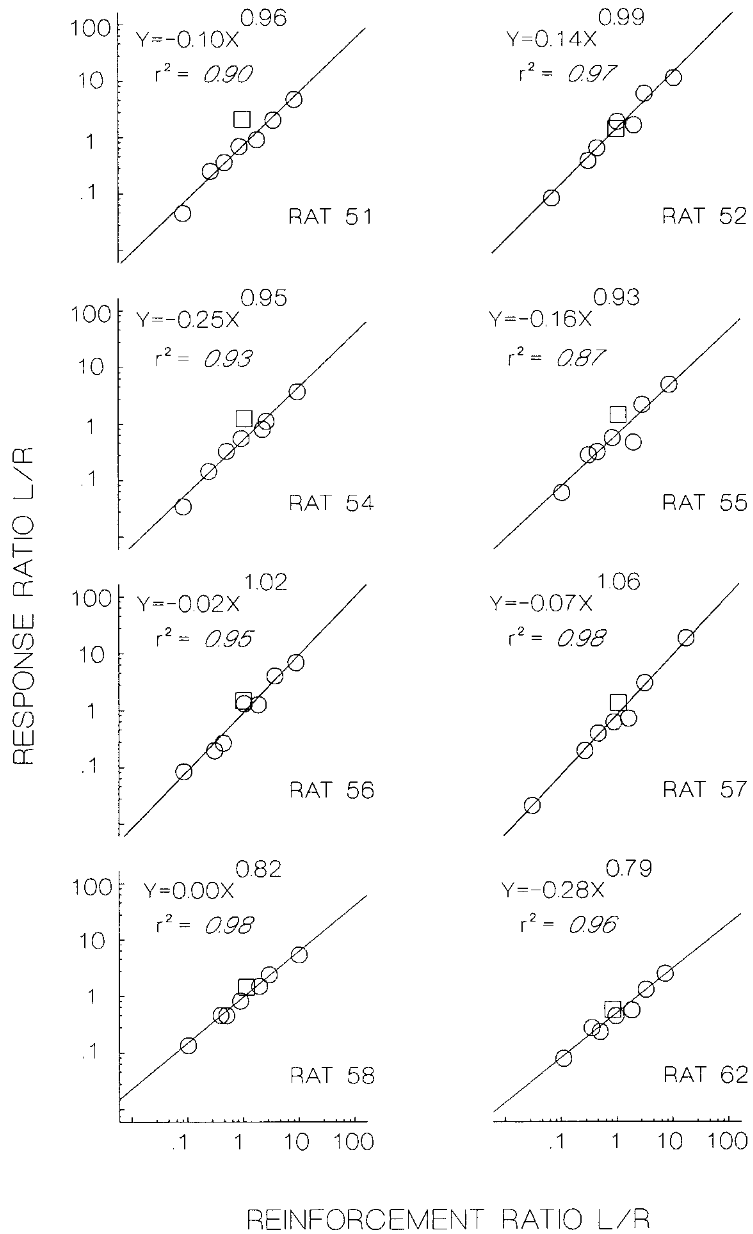

Fig. 2. The response ratios (left/right) as a function of the obtained reinforcer ratios plotted on log-log coordinates. The multiple panels show the data points generated by each rat responding with the 30.5-cm barrier in place. Other details are as in Figure 1.

the ratios of responses and residence time were entered into Equation 2 as the values of the dependent variable, and the logarithms of the ratios of obtained reinforcers were entered into Equation 2 as the values of the independent variable.

RESULTS

Because Rats 53, 59, 60, and 61 participated in Phase 1 only, their results will be reported separately. Figure 1 shows the ratios of responses and residence times against the

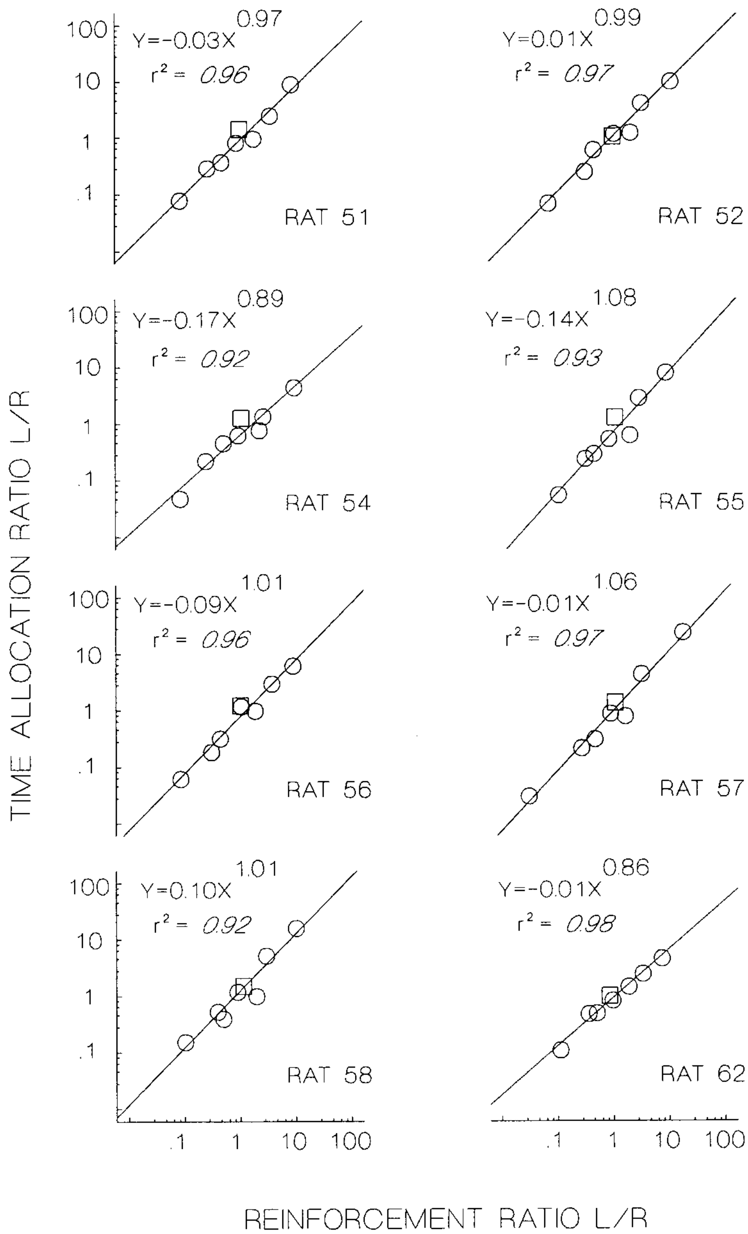

Fig. 3. The time-allocation ratios (left/right) as a function of obtained reinforcer ratios plotted on log-log coordinates. The multiple panels show the data points generated by each rat responding with the 30.5-cm barrier in place. Other details are as in Figure 1.

ratios of obtained reinforcers for these 4 subjects. Slopes ranged from 0.87 to 1.36 (mean slope of 1.12), showing a positive relation between the ratios of reinforcers and the ratios of responses and residence times. In general, Equation 2 fitted the data well, accounting for most of the variation in responses (mean r^2 of .95) and residence times (mean r^2 of .98). Except for Rat 61, the fitted equations showed negative intercepts, reflecting a bias for the right alternative.

We now consider the data of the 8 rats that participated in both phases. With the 30.5-cm barrier, a positive relation between the ratios

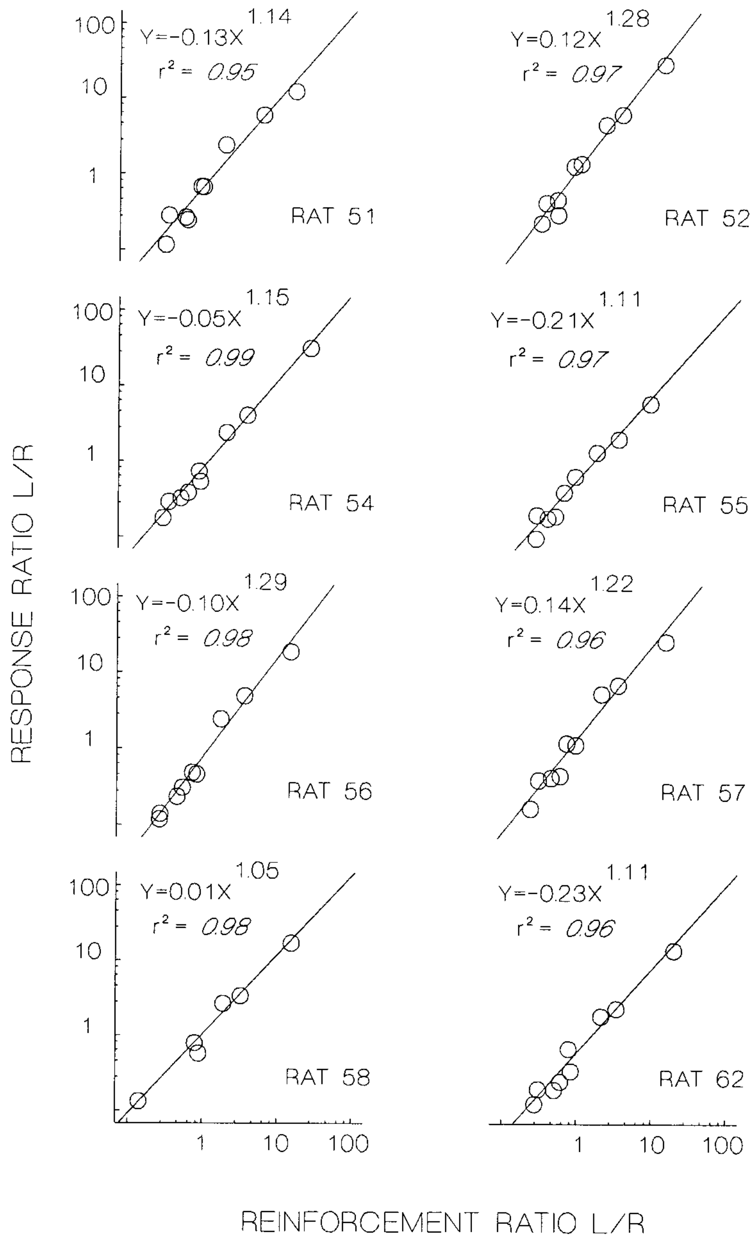

Fig. 4. The response ratios (left/right) as a function of obtained reinforcer ratios plotted on log-log coordinates. The multiple panels show the data points generated by each rat responding with the 45.7-cm barrier in place. Other details are as in Figure 1.

of reinforcers and the ratios of responses was observed (Figure 2). The slopes of the fitted lines varied from 0.79 to 1.06, with a mean slope of 0.94. The points of redetermination (squares) fell on the regression lines and close to the original determination. All fits were good, with r^2 values averaging .94. Except for Rats 52 and 58, the lines of best fit showed negative intercepts, reflecting a bias toward the right alternative.

Figure 3 shows that with the 30.5-cm barrier, the ratios of residence time generally matched the ratios of reinforcers. Slopes of the fitted lines ranged from 0.86 to 1.08

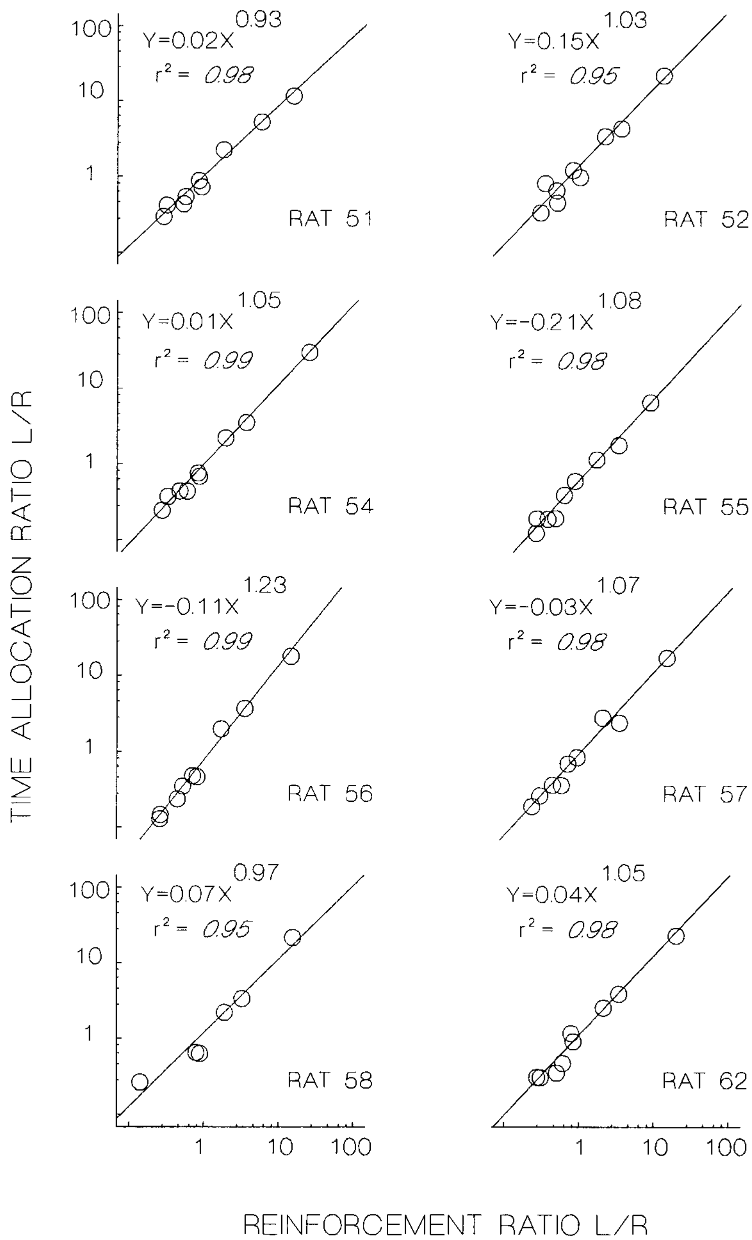

Fig. 5. The time-allocation ratios (left/right) as a function of obtained reinforcer ratios plotted on log-log coordinates. The multiple panels show the data points generated by each rat responding with the 45.7-cm barrier in place. Other details are as in Figure 1.

(mean slope of 0.98). Data from replicated schedules (squares) fell on the regression lines and were close to the original determinations. The regression lines fitted the data points well, with r^2 values averaging .95. Excepting Rats 52 and 58, a bias toward the right lever was evident across rats, the fitted equations having negative intercepts.

Figure 4 shows the relation between response and reinforcer ratios in Phase 2 with the 45.7-cm barrier. The fitted slopes ranged from 1.05 to 1.29 (mean slope of 1.17), show-

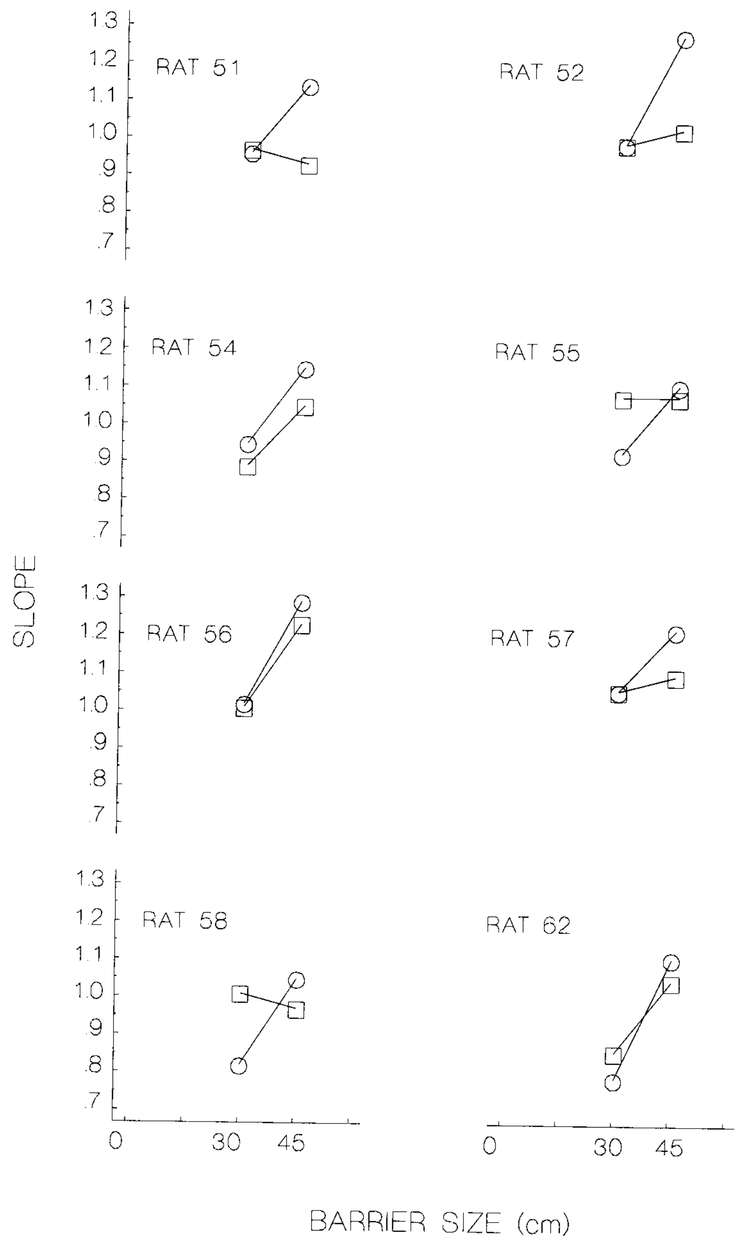

Fig. 6. The values of the best fitting slopes for the ratios of total presses (circles) and time allocation (squares) as a function of barrier size. Each panel represents the data points of a separate rat.

ing a positive relation between the ratios of obtained reinforcers and the ratios of responses. The negative intercepts of the fitted equations reflect a bias toward the right lever (with the exception of Rats 52, 57, and 58). In general, the lines fitted the data well, accounting for most of the variation in response ratios (mean r^2 of .97).

With the 45.7-cm barrier, the ratios of residence times overmatched the ratios of obtained reinforcers, as shown in Figure 5. The best fitting slopes varied from 0.93 to 1.23 (mean slope of 1.05). For Rats 51, 52, 54, 58, and 62 the fitted lines had positive intercepts, reflecting a bias toward the left lever. Rats 55, 56, and 57, however, showed negative inter-

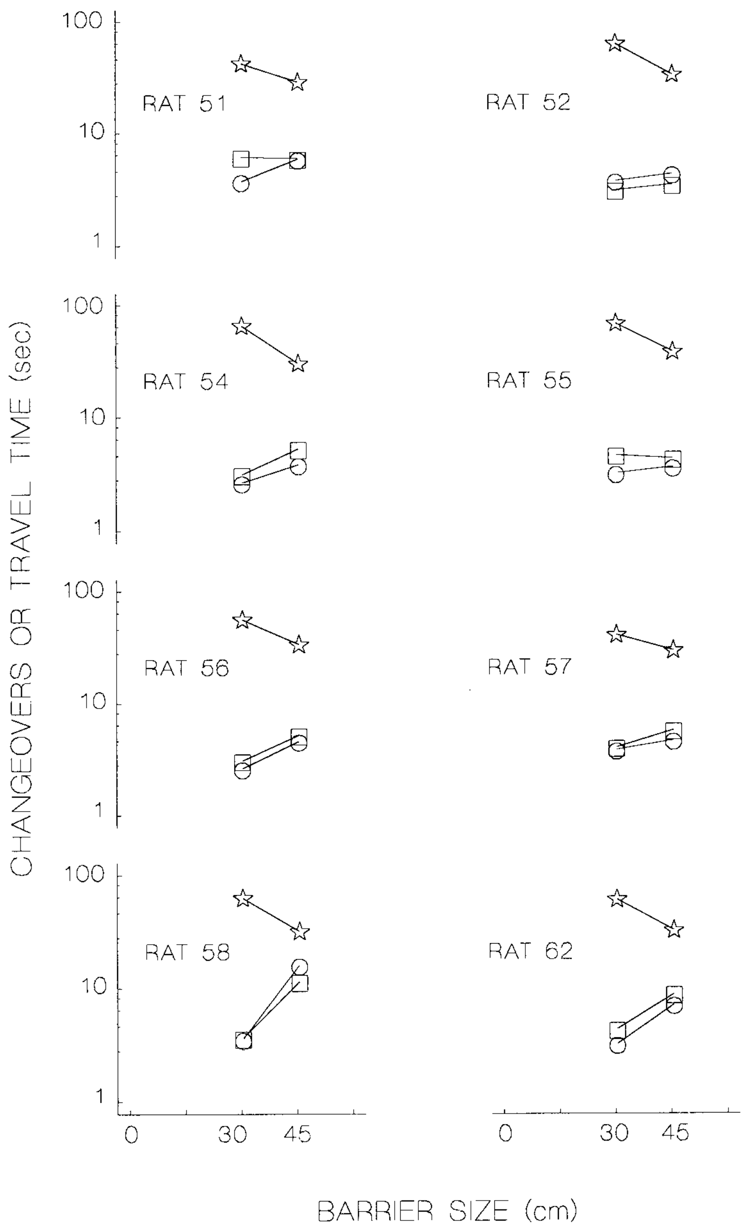

Fig. 7. The number of changeovers from one lever to the other (stars) and the travel time from left to right (squares) and from right to left (circles) as a function of barrier size. Each panel represents the data points of a separate rat. Note the logarithmic scale on the *y* axis.

cepts, reflecting a bias for the right lever. Overall, Equation 2 fitted the data well, accounting for most of the variation in the time-allocation ratios (mean r^2 of .98).

A comparison of Phases 1 and 2 revealed that sensitivity to reinforcement was enhanced. That is, raising the barrier from 30.5 cm to 45.7 cm caused ratios of responses and residence times to overmatch the ratios of reinforcers. The values of the slopes for the ratios of responses and those of residence times are plotted in Figure 6 against the size of the barriers used. In general, the slopes obtained with the 45.7-cm barrier were greater than 1.0, and the slopes obtained with the 30.5-cm barrier were close to 1.0. A sign test showed a significant difference (p = .008) in the slopes of response ratios across phases. However, no significant difference (p = .453) in the slopes of time-allocation ratios was observed.

Because not all RI schedules employed in Phase 2 were used in Phase 1, the differences in sensitivity observed across phases might have been caused by the ways in which the different schedules affected reinforcement rate across Phases 1 and 2. To examine this possibility, only the data obtained with the same pairs of schedules (60-60, 30-90, 90-30, and 15-120) were used to compute the parameters of sensitivity (s), bias (b), and goodness of fit (r^2) for response and time-allocation ratios.

Whether the parameters were computed over the same schedules or over all schedules, Equation 2 yielded similar results. For the ratios of responses and time allocation, sensitivity to reinforcement was enhanced by increasing the barrier height from 30.5 to 45.7 cm (median difference in sensitivity was 0.22; 14 positive differences over 16 cases). The goodness of fit remained high in all cases (median r^2 = .99; minimum r^2 = .96, maximum r^2 = 1.0). A bias toward the right lever was generally observed across schedules and barrier heights.

Figure 7 shows changeovers from one lever to the other (stars) and the travel times from the left side to the right side (squares) and vice versa (circles) as a function of barrier height. Increasing the barrier height from 30.5 to 45.7 cm increased the mean travel times and decreased the number of changeovers.

DISCUSSION

The present study supports the idea that choice situations with costly locomotion lead to overmatching. In Phase 1, when the rats were required to climb over a 30.5-cm barrier to travel from one alternative to the other, their behavior conformed to Baum's (1974) generalized matching law. For every rat, the response and time-allocation ratios matched the reinforcement ratios provided by the schedules. Interestingly, for 5 of 12 rats, the slopes of response and time-allocation ratios were above 1.0. These results are consistent with those reported in previous studies with great tits (Krebs, Kacelnik, & Taylor, 1978; Ydenberg, 1984), pigeons (Baum, 1982; Boelens & Kop, 1983), and rats (Aparicio & Baum, 1997) when the experimental situation included travel.

Phase 2 increased the travel requirement from one alternative to the other by raising the height of the barrier from 30.5 to 45.7 cm. The rationale was to increase the difficulty of travel. For response and time-allocation ratios, the generalized matching law showed slopes above 1.1 (above 1.2 for some rats). That is, with a 45.7-cm barrier obstructing passage from one alternative to the other, the response and time-allocation ratios overmatched the reinforcement ratios. Thus, a more costly travel requirement enhanced sensitivity to reinforcement. This result resembles the effects of placing hurdles between two response alternatives in Baum's (1982) experiment with pigeons, and extends the generality of this finding to the study of choice in rats.

Evidence that the 45.7-cm barrier increased the difficulty of travel was obtained by analyzing changes in travel times and numbers of changeovers. When barrier height was raised from 30.5 to 45.7 cm, the number of changeovers from one lever to the other decreased, and travel times increased. These results are consistent with those obtained in previous studies (Aparicio, 1998, 1999) conducted in this laboratory, and support the conclusion that climbing during travel has large effects on rats' choices (Aparicio & Baum, 1997; Baum & Aparicio, 1999).

In sum, the results of the current experiment support the utility of using the barrier choice paradigm to study foraging-related choices in rats. When the situation requires costly locomotion to travel from one alternative (patch) to another (i.e., the cost of searching for food increases), sensitivity to reinforcement is enhanced.

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Received March 31, 2000
Final acceptance November 10, 2000

APPENDIX A

For each rat, all concurrent schedules used, number of responses (presses), reinforcers obtained (rft), travel times (travel), and number of changeovers (CO). Data are five-session means obtained with the 30.5-cm barrier. Times are in seconds.

		Left lever					Right lever				
Rat	Schedule	Presses	Time	Rft	Travel	CO	Presses	Time	Rft	Travel	CO
51	1	322.60	690.66	28.40	239.89	62.80	430.80	790.97	31.60	258.75	62.60
	2	493.00	967.57	47.00	177.93	39.60	224.20	367.99	13.00	142.00	39.20
	3	319.40	687.64	53.80	99.78	30.80	62.20	72.02	6.20	103.47	30.60
	4	592.80	979.14	29.40	224.12	53.20	262.40	639.92	28.80	225.23	53.40
	5	176.00	291.73	12.80	117.48	42.00	647.40	944.22	47.20	209.07	42.00
	6	34.60	63.64	4.80	27.73	11.60	705.00	761.22	55.20	35.41	12.00
	7	485.80	838.04	25.40	205.36	57.20	489.80	815.39	13.80	769.04	56.80
	8	255.80	541.67	13.40	244.08	43.60	655.80	1,369.71	27.60	558.16	44.00
52	1	761.80	742.10	31.00	307.64	75.20	371.80	599.75	29.00	75.60	380.69
	2	1,108.60	1,009.04	46.00	144.34	44.20	170.60	230.77	14.00	44.20	137.55
	3	952.00	643.04	55.00	72.54	27.80	77.40	60.72	5.00	27.00	82.91
	4	1,385.20	263.68	30.20	275.98	96.40	901.00	727.49	29.80	96.40	206.37
	5	505.40	263.68	14.60	164.12	59.80	1,221.80	1,000.33	45.40	60.20	160.31
	6	80.40	52.00	4.00	29.83	11.20	895.40	713.50	56.00	12.00	29.48
	7	1,400.60	1,049.20	31.80	449.42	101.40	785.40	811.43	15.00	102.20	329.01
	8	831.40	699.59	13.20	641.33	87.60	1,192.40	1,093.55	28.60	87.40	277.17
53	1	282.40	597.53	29.60	290.51	65.20	507.00	879.10	30.40	388.25	65.80
	2	495.40	883.67	44.80	172.43	43.40	185.40	304.46	15.20	172.87	43.40
	3	504.40	705.09	53.40	62.66	17.40	48.00	68.95	6.60	53.63	16.80
	4	673.40	821.23	30.80	292.04	65.40	553.40	768.07	28.00	186.15	65.60
	5	140.40	286.50	13.00	146.60	26.60	545.00	1,127.62	47.00	99.02	26.40
	6	0.40	8.36	1.00	3.68	0.20	205.20	1,164.20	59.80	12.51	1.20
	7	402.20	1,210.92	26.40	267.13	39.20	238.40	960.77	15.00	200.69	39.00
	8	190.60	721.15	13.80	274.90	38.00	399.00	1,511.28	25.20	191.13	38.00

APPENDIX A

(*Continued*)

Rat	Schedule	Left lever Presses	Left lever Time	Left lever Rft	Left lever Travel	Left lever CO	Right lever Presses	Right lever Time	Right lever Rft	Right lever Travel	Right lever CO
54	1	417.20	594.45	29.40	263.42	82.60	692.20	879.77	30.60	294.34	82.60
	2	466.40	682.77	43.80	188.35	70.20	382.20	465.40	16.20	255.97	69.80
	3	526.20	641.67	54.40	71.03	31.80	130.40	133.73	5.60	78.12	31.40
	4	1,008.40	925.17	31.20	185.47	85.40	742.60	676.42	28.80	203.74	84.80
	5	219.00	224.87	12.00	121.16	53.80	1,395.00	947.72	48.00	148.71	54.00
	6	47.00	36.00	4.80	47.23	19.20	1,266.40	708.22	55.20	51.46	19.60
	7	801.00	884.02	30.40	315.06	93.00	911.20	1,058.16	13.20	378.52	92.80
	8	431.60	690.73	15.60	278.97	92.20	1,206.00	1,404.94	30.00	321.99	92.00
55	1	206.40	462.89	27.80	384.80	83.60	336.20	802.37	32.20	518.63	83.40
	2	390.40	783.18	44.80	225.21	74.20	165.20	253.36	15.20	251.03	73.80
	3	331.20	579.12	54.00	136.60	41.60	61.80	67.07	6.00	193.52	41.40
	4	444.40	850.21	30.60	313.46	86.60	283.60	607.75	27.80	295.31	86.60
	5	185.80	239.00	14.60	168.58	62.20	611.40	933.52	45.40	210.73	62.20
	6	43.20	42.41	5.80	51.02	25.40	662.20	728.08	54.20	62.42	26.00
	7	301.00	644.12	30.80	279.41	88.40	588.80	956.86	15.00	743.32	88.00
	8	248.40	456.11	13.40	306.12	88.00	715.40	1,461.02	29.00	476.91	88.40
56	1	779.40	796.90	30.80	340.83	98.40	545.60	623.22	29.20	351.46	99.00
	2	1,259.20	933.72	47.40	129.28	52.00	287.40	290.98	12.60	138.32	51.40
	3	909.00	657.86	54.00	60.14	27.00	120.60	99.09	6.00	52.68	26.00
	4	1,256.00	939.76	30.00	210.33	76.20	780.20	712.45	29.00	193.99	75.80
	5	245.00	203.05	14.20	91.36	45.80	1,146.20	1,016.93	45.80	96.38	46.00
	6	68.60	50.17	4.80	31.36	15.20	752.20	750.75	55.20	32.52	15.80
	7	945.40	1,012.21	27.20	227.99	76.00	691.20	951.91	14.40	449.20	76.00
	8	446.40	575.80	14.60	193.77	62.40	1,543.20	1,678.98	32.80	246.31	63.00
57	1	327.40	706.75	28.40	357.49	51.60	489.80	756.70	31.60	230.13	51.00
	2	576.00	967.09	45.80	188.19	35.60	176.60	207.63	14.20	137.57	34.60
	3	628.00	856.96	56.80	23.67	5.40	31.40	33.47	3.20	12.99	4.80
	4	895.60	1,008.63	31.20	215.60	60.20	615.00	688.35	28.80	203.25	59.60
	5	328.20	256.97	12.80	76.24	31.40	1,559.20	1,122.80	47.20	81.23	31.80
	6	26.00	27.03	1.80	14.97	6.80	1,150.00	840.35	58.20	17.73	7.80
	7	914.80	981.47	26.00	208.26	66.20	1,181.60	1,168.34	15.80	277.09	66.60
	8	465.80	455.44	15.00	211.91	73.80	1,092.20	1,374.57	31.80	652.04	73.20
58	1	420.20	736.16	28.40	344.43	87.20	471.80	573.20	31.60	442.27	87.40
	2	480.00	1,081.38	44.80	163.47	49.00	184.80	193.91	15.20	202.62	49.00
	3	331.40	789.34	54.60	59.81	19.80	56.80	46.07	5.40	60.18	19.00
	4	692.00	961.99	32.00	264.16	72.40	441.00	595.22	27.80	300.77	72.60
	5	416.80	426.60	17.00	180.16	70.60	836.80	752.75	43.00	173.65	70.80
	6	141.20	105.53	5.60	64.96	30.00	967.80	641.16	54.40	71.91	30.20
	7	799.20	987.13	28.00	401.84	81.00	492.00	919.86	14.20	327.81	81.40
	8	416.80	545.69	14.40	484.52	95.40	846.40	1,279.02	28.80	389.47	96.00
59	1	395.20	391.13	22.60	462.82	60.80	431.80	509.15	17.20	195.54	61.00
	2	868.00	740.48	45.80	200.76	83.60	336.00	314.07	14.20	216.45	83.40
	3	919.00	626.54	53.40	88.75	37.40	109.00	82.39	6.60	97.20	36.60
	4	503.40	670.22	27.60	266.38	64.00	655.00	983.33	29.60	278.73	64.00
	5	92.00	86.34	13.80	157.59	38.80	653.40	1,244.85	46.20	184.81	39.20
	6	31.80	27.12	5.40	65.28	17.80	491.00	789.43	54.60	55.24	17.80
	7	358.40	692.85	28.20	487.49	78.80	616.00	1,035.57	16.00	417.40	79.20
	8	202.80	479.78	15.20	369.16	63.40	826.80	1,569.73	32.20	278.16	64.00
60	1	821.00	623.21	28.80	262.23	75.60	749.00	860.70	31.20	243.57	75.80
	2	1,404.00	936.39	45.00	164.34	53.60	326.40	289.23	15.00	125.00	53.40
	3	1,088.60	723.00	55.20	44.70	14.80	65.80	60.70	4.80	33.89	14.60
	4	686.80	827.63	30.60	393.30	56.80	574.20	621.27	28.80	223.15	57.00
	5	220.60	310.23	12.40	137.52	31.60	1,540.60	1,053.04	47.60	89.73	32.20
	6	17.00	27.57	2.60	18.06	3.80	1,380.60	837.85	57.40	10.47	4.60
	7	729.40	1,193.61	26.40	272.21	48.60	1,017.00	969.69	14.80	200.63	49.00
	8	273.40	600.74	14.40	375.84	52.80	1,340.40	1,415.90	30.40	300.57	53.80

APPENDIX A

(*Continued*)

Rat	Schedule	Left lever Presses	Left lever Time	Left lever Rft	Left lever Travel	Left lever CO	Right lever Presses	Right lever Time	Right lever Rft	Right lever Travel	Right lever CO
61	1	592.20	791.18	29.00	303.75	70.60	431.20	877.56	31.00	342.77	71.00
	2	1,020.20	921.36	45.20	185.40	52.60	196.80	223.19	14.80	191.05	52.00
	3	833.40	687.77	54.20	71.28	26.60	93.80	76.45	5.80	84.87	26.40
	4	849.60	798.06	29.80	216.55	82.00	602.00	693.30	30.20	345.21	81.80
	5	451.00	381.81	15.40	164.12	61.00	824.40	733.92	44.60	265.97	60.80
	6	127.40	119.83	6.40	70.85	25.80	661.00	626.53	53.60	99.98	26.40
	7	749.80	1,130.14	31.00	290.44	86.80	674.00	816.80	15.40	394.88	86.60
	8	435.80	789.69	15.20	306.59	95.00	838.60	1,155.40	31.40	445.67	95.80
62	1	272.40	645.07	29.40	314.86	67.20	569.40	725.24	30.60	354.98	67.20
	2	376.00	792.51	46.20	193.95	58.00	268.20	300.28	13.80	250.81	57.20
	3	314.20	636.37	52.80	83.00	36.20	117.20	129.61	7.20	116.96	35.20
	4	410.40	821.46	27.20	193.32	70.40	663.00	767.03	32.00	275.69	70.60
	5	204.20	389.24	15.80	150.98	59.40	691.00	761.23	44.20	215.79	60.00
	6	51.60	75.34	6.00	70.68	26.20	607.00	649.94	54.00	88.95	27.00
	7	378.00	1,168.41	31.00	278.72	78.40	625.20	750.67	16.60	437.24	78.40
	8	227.40	630.02	14.80	363.37	94.20	903.40	1,194.12	29.40	507.37	94.60

APPENDIX B

For each rat, all concurrent schedules used, number of responses (presses), reinforcers obtained (rft), travel times (travel), and number of changeovers (CO). Data are five-session means obtained with the 45.7-cm barrier. Times are in seconds.

Rat	Schedule	Left lever Presses	Left lever Time	Left lever Rft	Left lever Travel	Left lever CO	Right lever Presses	Right lever Time	Right lever Rft	Right lever Travel	Right lever CO
51	1	545.80	868.70	28.60	148.30	36.40	770.00	1,128.16	31.40	194.73	36.40
	2	951.80	1,264.04	51.20	62.54	14.20	152.20	227.00	8.80	56.73	13.80
	3	582.60	804.43	56.40	23.54	6.20	45.00	65.22	3.60	31.96	5.80
	4	955.60	1,225.30	38.60	122.34	28.20	381.60	513.29	21.40	156.41	28.20
	5	604.60	1,009.64	19.80	296.65	43.60	851.20	1,082.05	23.60	296.35	43.60
	6	338.60	665.91	13.80	276.75	33.60	1,133.80	1,503.96	44.40	198.98	33.60
	7	122.80	368.31	13.20	144.43	17.40	1,000.00	1,174.62	46.80	139.85	17.60
	8	282.20	552.89	20.60	202.59	28.20	1,003.60	1,195.21	39.40	182.29	28.20
	9	406.60	953.87	12.00	221.33	35.40	1,563.40	1,663.63	21.60	222.58	35.60
52	1	1,375.20	876.96	30.20	204.96	49.80	932.20	844.19	29.80	153.68	49.60
	2	1,483.40	1,130.39	47.00	113.48	29.80	225.20	245.54	13.00	82.58	29.00
	3	974.00	822.90	55.80	40.72	9.20	31.60	35.25	4.20	25.94	8.60
	4	1,737.80	1,259.86	41.20	173.33	38.80	361.40	347.29	18.80	116.79	38.60
	5	1,173.20	1,274.70	20.40	254.79	52.20	860.20	986.62	25.00	178.79	52.20
	6	604.40	1,100.41	15.00	164.06	35.80	1,347.80	1,267.33	43.40	133.01	35.60
	7	294.00	381.03	13.80	98.03	26.60	1,211.80	1,070.10	46.20	90.47	26.60
	8	394.00	596.73	20.00	113.39	27.00	1,260.80	1,243.33	40.00	100.28	27.20
	9	435.00	1,120.90	10.00	158.39	32.40	884.40	1,605.43	20.40	176.47	33.40
54	1	541.80	728.06	27.80	165.05	49.60	956.20	994.46	32.20	226.76	49.80
	2	1,112.80	1,128.45	47.20	60.80	22.00	257.40	299.21	12.80	90.29	21.60
	3	725.00	865.70	58.20	11.26	3.60	21.80	27.26	2.25	16.95	3.20
	4	1,070.00	1,359.33	39.60	111.95	32.40	419.60	576.42	20.40	118.53	32.00
	5	595.00	1,010.68	20.40	196.47	47.20	766.60	1,252.83	24.80	233.91	47.00
	6	311.60	598.56	14.60	227.24	43.80	1,019.80	1,516.35	45.00	277.43	44.00
	7	178.60	281.24	12.80	95.03	24.40	957.00	1,085.82	47.20	136.13	25.20
	8	316.00	555.82	19.20	103.66	24.80	924.80	1,189.67	40.80	142.73	25.40
	9	237.00	851.69	12.40	118.81	26.00	585.80	1,828.87	21.00	252.01	26.20

APPENDIX B

(*Continued*)

Rat	Schedule	Left lever Presses	Left lever Time	Left lever Rft	Left lever Travel	Left lever CO	Right lever Presses	Right lever Time	Right lever Rft	Right lever Travel	Right lever CO
55	1	398.40	615.09	28.20	209.47	57.40	586.60	960.52	31.80	192.44	57.40
	2	699.00	851.90	46.40	114.62	42.60	325.40	445.67	13.60	142.14	42.20
	3	684.40	679.31	54.00	43.63	19.00	108.20	96.76	6.00	59.29	18.60
	4	727.60	904.34	38.00	146.68	49.00	510.20	734.63	22.00	184.62	48.60
	5	353.40	658.67	18.40	204.69	60.20	846.60	1,577.02	29.00	254.47	59.80
	6	200.20	370.53	12.80	167.98	43.60	958.20	1,812.31	47.20	173.05	44.20
	7	83.40	165.47	12.60	97.96	24.00	812.60	1,263.70	47.40	111.02	24.80
	8	142.60	294.03	16.60	123.87	28.20	754.60	1,455.10	43.40	139.07	28.80
	9	110.40	471.69	9.60	112.02	20.40	546.00	2,293.42	19.80	161.80	21.00
56	1	655.60	617.95	26.80	176.52	39.60	1,340.80	1,252.81	33.20	199.97	39.80
	2	1,441.00	1,069.80	46.80	121.71	30.40	278.80	274.50	13.20	118.88	30.00
	3	1,059.40	818.36	56.20	24.74	7.20	53.60	43.22	3.80	19.99	6.60
	4	1,366.80	1,118.70	37.80	154.75	41.60	531.00	532.18	22.20	204.63	41.20
	5	637.40	689.95	19.20	311.50	58.80	1,240.00	1,354.04	27.20	343.54	59.00
	6	202.00	232.52	12.20	179.90	38.00	1,595.40	1,690.16	47.40	210.18	38.60
	7	167.60	179.42	12.40	128.13	27.20	1,124.60	1,151.46	47.60	152.05	28.20
	8	313.00	337.41	18.40	135.34	26.40	1,258.40	1,342.75	41.60	161.49	26.40
	9	360.00	691.09	10.80	231.51	36.80	1,099.40	1,858.68	20.80	274.52	37.00
57	1	933.60	780.04	29.20	145.39	38.60	773.20	871.43	30.80	171.19	38.80
	2	1,063.20	1,153.57	44.80	113.45	14.80	144.80	454.64	12.80	170.25	14.20
	3	1,171.60	784.25	57.00	22.68	6.80	42.40	43.28	3.75	22.85	6.60
	4	1,753.00	1,201.94	40.60	155.22	38.20	312.00	407.42	19.40	178.83	38.00
	5	1,010.00	955.04	18.60	209.63	51.00	800.00	1,291.91	26.00	240.83	50.60
	6	496.00	450.12	13.80	166.98	39.80	1,194.40	1,605.91	46.00	203.57	40.20
	7	227.20	222.41	11.40	82.90	19.40	1,282.40	1,098.80	48.60	99.93	20.00
	8	369.20	523.58	18.40	113.12	22.80	825.80	1,348.22	41.60	137.28	23.40
	9	458.80	712.20	11.00	216.53	37.80	969.20	1,853.62	18.80	255.79	38.20
58	1	415.40	687.81	28.20	179.25	46.80	679.80	1,031.78	31.80	193.82	46.80
	2	809.40	1,020.23	46.00	122.69	30.80	225.00	286.02	14.00	103.52	30.40
	3	587.20	833.55	56.40	33.42	6.60	32.40	36.24	3.60	22.60	6.00
	4	930.80	1,170.66	39.40	193.79	48.20	328.80	499.03	20.60	180.11	48.00
	5	572.40	890.92	22.00	279.04	59.00	681.00	1,287.73	27.80	250.05	59.20
	6	23.60	447.77	3.60	210.15	2.80	167.20	1,592.17	25.60	129.36	2.60
62	1	216.00	789.98	27.60	238.24	51.20	593.20	815.65	32.40	383.55	51.80
	2	412.60	1,119.33	46.60	101.25	23.20	166.00	270.19	13.40	197.78	23.40
	3	413.00	835.99	57.20	23.77	6.60	27.80	34.15	2.80	27.95	6.00
	4	532.60	1,208.42	41.00	188.71	36.60	271.60	445.80	19.00	257.11	36.20
	5	361.80	1,078.46	19.20	346.40	48.00	501.60	865.52	24.20	406.61	48.00
	6	187.40	466.74	13.60	347.27	47.80	894.20	1,437.53	44.20	380.67	48.20
	7	90.40	363.07	13.00	302.81	23.40	680.00	1,108.44	47.00	259.56	24.20
	8	134.60	443.41	20.20	198.48	29.20	655.00	1,184.54	39.80	307.11	29.20
	9	135.00	765.78	12.00	340.67	27.40	512.60	1,531.22	19.60	413.89	27.20